

For Chengdu Workshop on ASIAEX 2001

**Characteristic of the Internal Waves at
Location of $126^{\circ}54.32'E/ 29^{\circ}24.01'N$**

Shihong ZHOU

(Dalian Scientific Test & Control Technology Institute, China)

Jixun ZHOU Jie YANG

(Georgia Institute of Technology, Atlanta, USA)

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What the topic focuses on?

**❑ Observation of Internal Waves in ECS
ASIAEX 2001**

❑ Features of the Temperature Fluctuation

**❑ Characteristic of the Vertical Displacement
Power Spectrum of Internal Waves**

**❑ Normal mode of internal wave and its
dispersion including Phase velocities, group
velocities, and eigenfunctions of normal
modes**

1. Introduction

Experiment Site:

126°54.32'E/29°24.01'N

Water depth of sea area: ~ 105m

2. Observation of Internal Waves

Survey Duration:

~ 63 hours from 08:40/Jun.3 to 0:00/Jun.6/2001

Survey Instruments:

17 WaDar Temperature Sensors from GIT

Sensor depths:

**19.95, 23.1, 26.25, 29.4, 32.55, 35.7, 38.85, 42, 45.15,
48.3, 51.45, 54.6, 57.75, 60.9, 65.1, 71.4 and 79.8m**

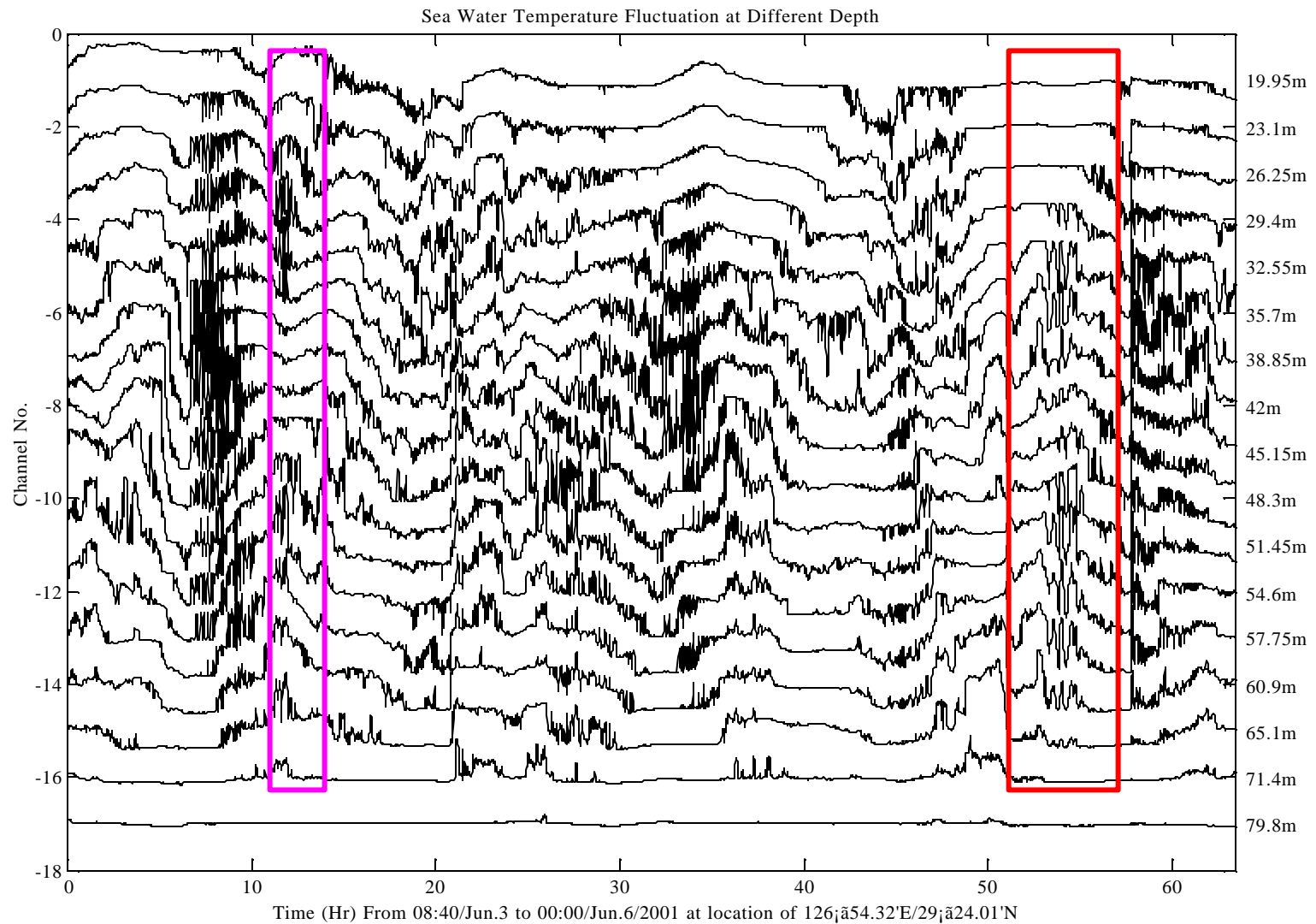


Figure 1 Sea water temperature data curves at different depth from 08:40/Jun.3 to 00:00/Jun.6/2001

Features of the Temperature Fluctuation:

- ❑ Three elevation solitons at 53:15, 53:46 and 54:14 which are separated from internal tides**
- ❑ Thermocline Layer: from 20m to 75m**
- ❑ Internal semi-diurnal tides with strong fluctuations at 8:00, 21:00, 33:00, 46:00 and 58:00**
- ❑ Cool water-mass between 11:48 and 13:52**

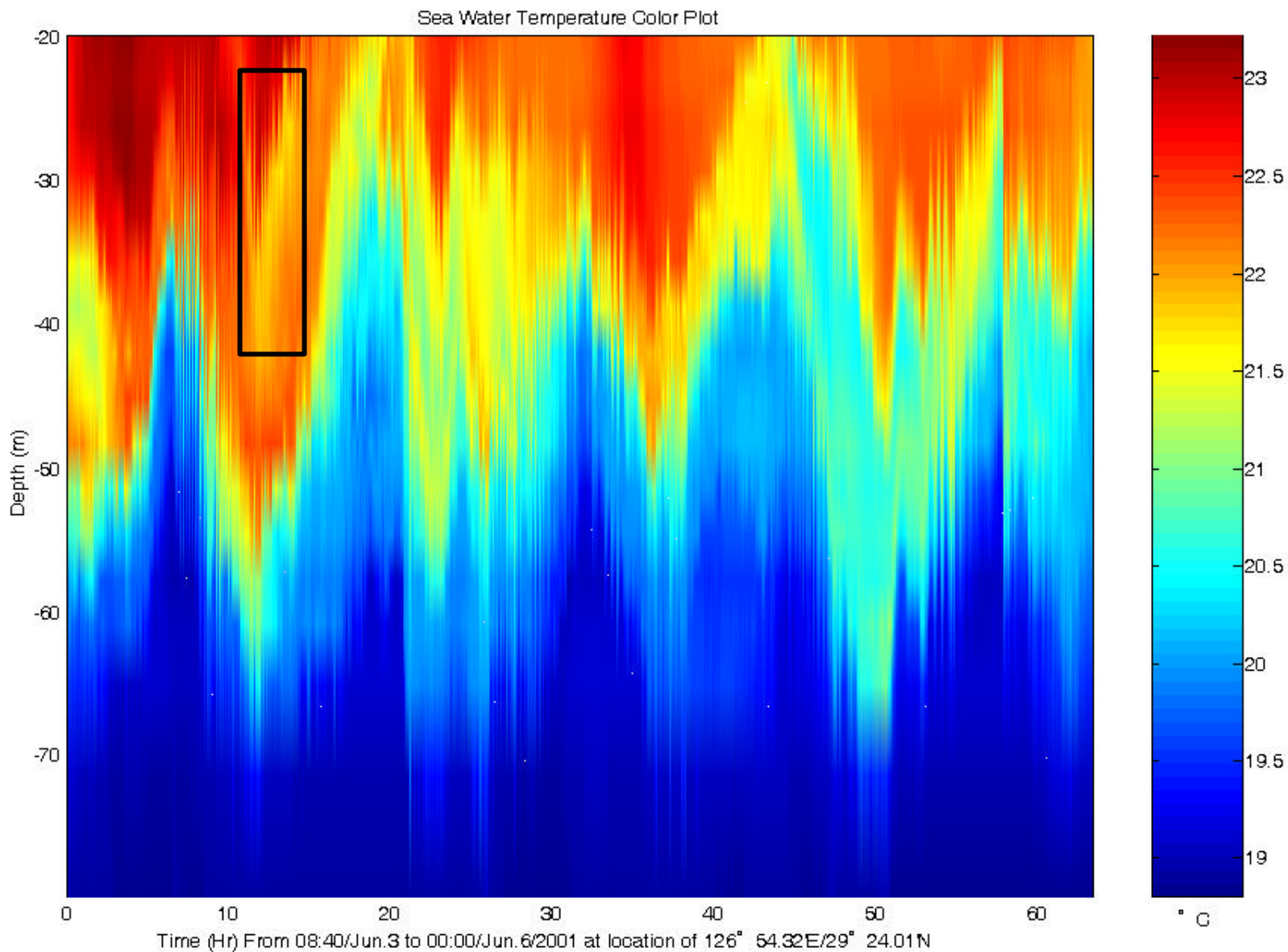


Figure 2 Sea water temperature distribution plot at different depth from 08:40/Jun.3 to 00:00/Jun.6/2001

3. Characteristic of the Vertical Displacement Power Spectrum of Internal Waves

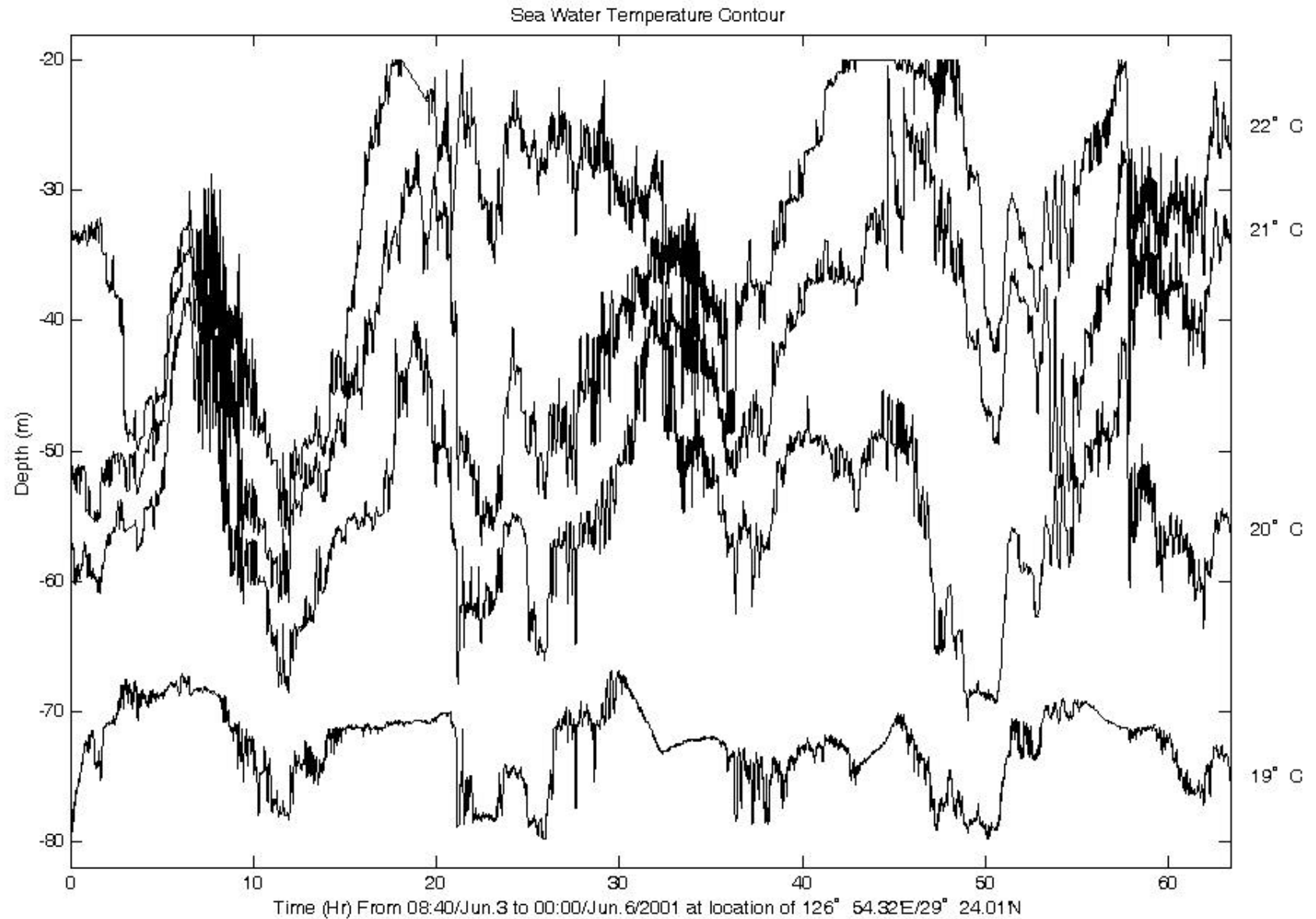
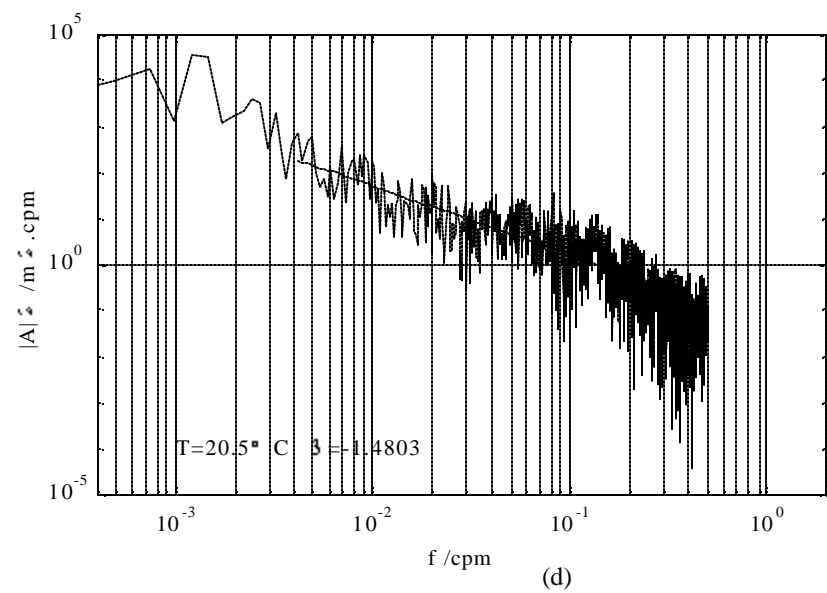
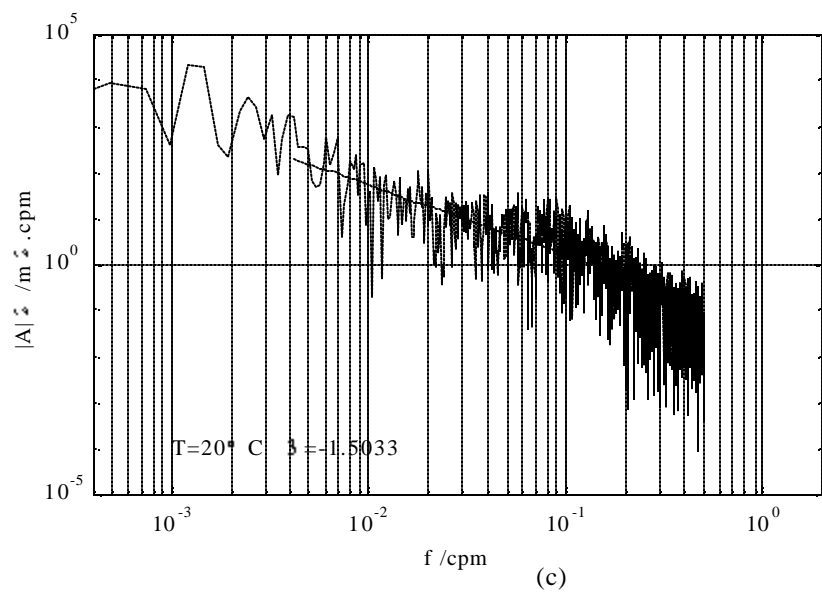
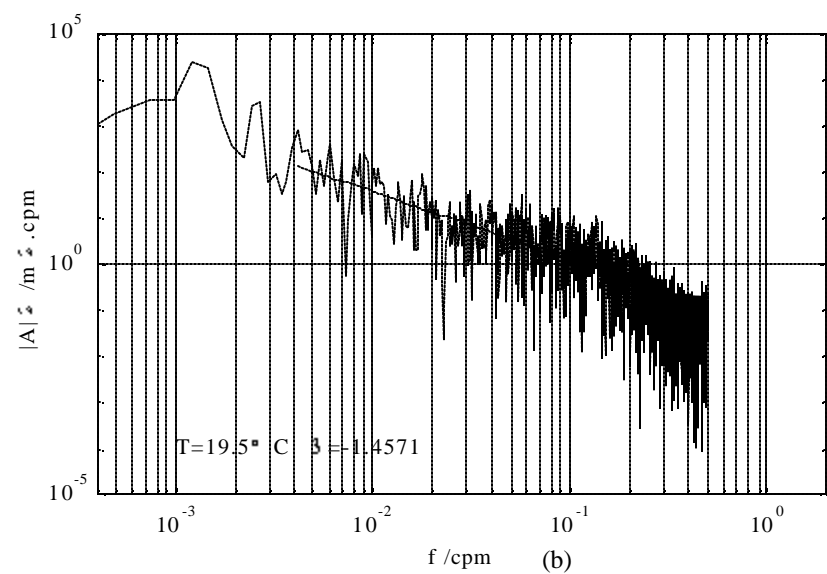
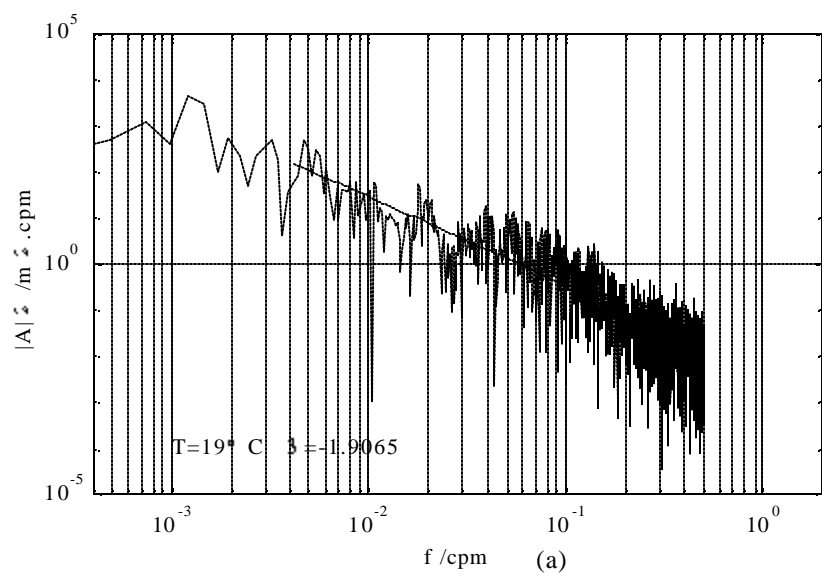


Figure 3 Vertical displacement curves at different temperature from 08:40/Jun.3 to 00:00/Jun.6/2001



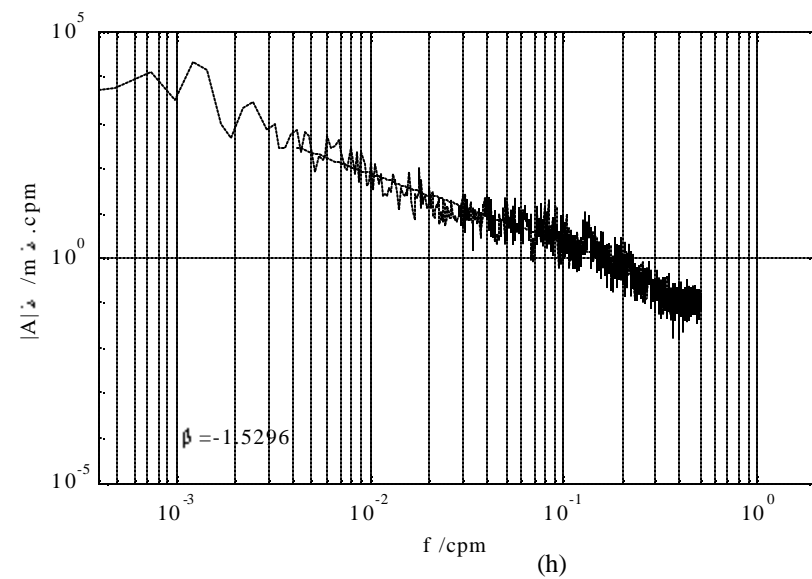
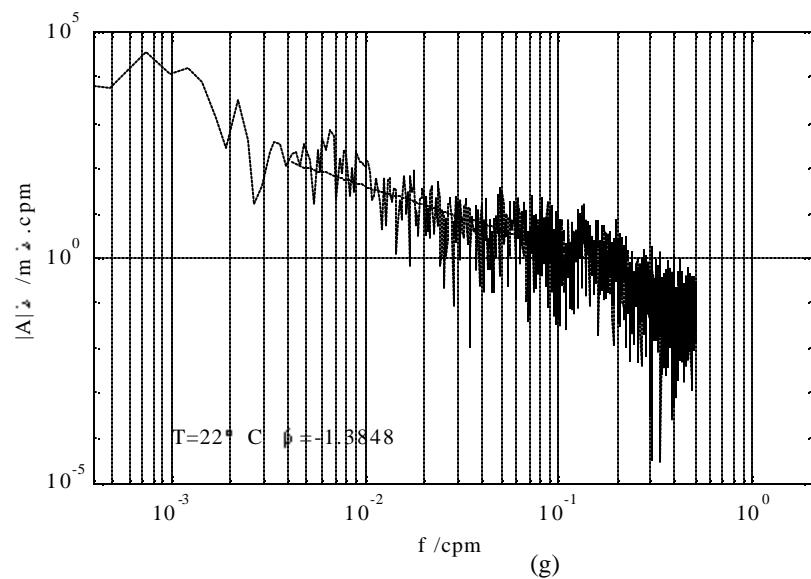
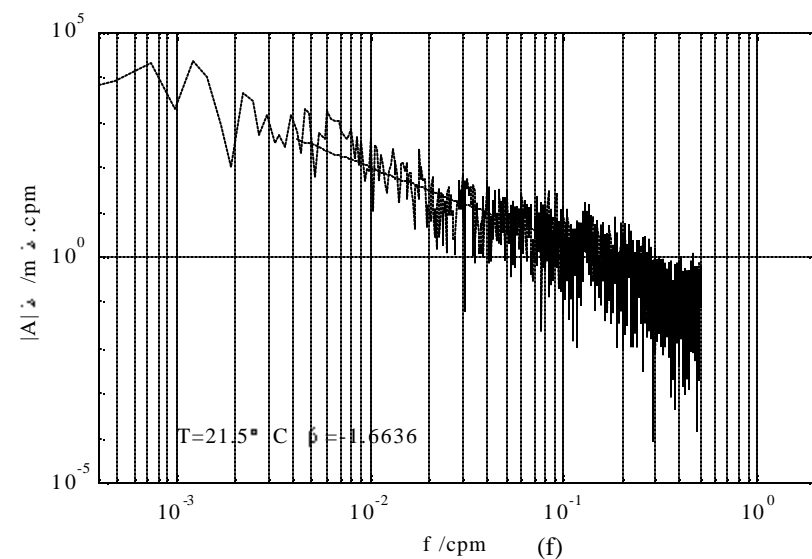
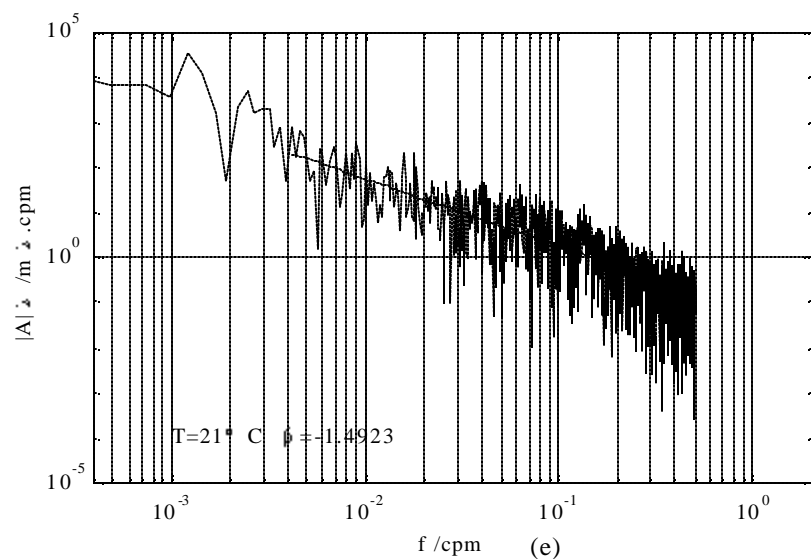


Figure 4 Power spectrum of vertical particle displacement at different temperature

Table 1 The attenuation coefficients of vertical displacement power spectrum at different temperature

T(°C)	19	19.5	20	20.5	21	21.5	22
<i>b</i>	1.9065	1.4571	1.503	1.4803	1.4923	1.6636	1.3848

During the frequency range of $w_i < w < N(z)$, the spectrum attenuation coefficients of the vertical displacement power spectrum are about -1.5

□Inertial frequency: $w_i = 2\Omega \sin j = 0.0043\text{cpm}$

□Brunt-Vaisala's frequency: $N(z)$

4. Normal mode of internal wave and its dispersion

Wave Equation of internal wave:

$$\frac{\partial^2 \mathbf{y}_j(z)}{\partial z^2} + \left[\frac{N^2(z) - \omega^2}{\omega^2 - \omega_i^2} \right] k_{hj}^2 \mathbf{y}_j(z) = 0$$

k_{hj} : horizontal wave-number of j^{th} normal mode of internal wave

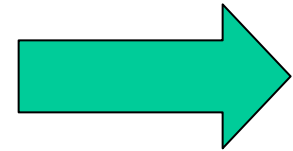
Brunt-Vaisala's frequency:

$$N^2(z) = - \frac{g}{\mathbf{r}(z)} \frac{\partial \mathbf{r}(z)}{\partial z} = a g \frac{\partial T(z)}{\partial z} - b g \frac{\partial S(z)}{\partial z}$$

Eigenfunction Approximation by Talor's Series Expansion:

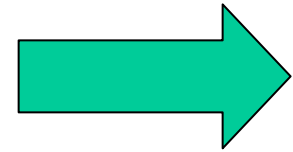
$$\mathbf{y}_j^{n+1} = \mathbf{y}_j^n + \mathbf{y}_j^{n'} h + \mathbf{y}_j^{n''} \frac{h^2}{2!} + \mathbf{y}_j^{n'''} \frac{h^3}{3!} + \dots$$

$$\mathbf{y}_j^{n-1} \approx \mathbf{y}_j^n - \mathbf{y}_j^{n'} h + \mathbf{y}_j^{n''} \frac{h^2}{2!} - \mathbf{y}_j^{n'''} \frac{h^3}{3!} + \dots$$



$$\mathbf{y}_j^{n'} \approx \frac{\mathbf{y}_j^{n+1} - \mathbf{y}_j^n}{h} + \left[\frac{N^2(z_n) - \mathbf{w}^2}{\mathbf{w}^2 - \mathbf{w}_i^2} \right] k_{hj}^2 \mathbf{y}_j^n \frac{h}{2}$$

$$\mathbf{y}_j^{n'} \approx \frac{\mathbf{y}_j^n - \mathbf{y}_j^{n-1}}{h} - \left[\frac{N^2(z_n) - \mathbf{w}^2}{\mathbf{w}^2 - \mathbf{w}_i^2} \right] k_{hj}^2 \mathbf{y}_j^n \frac{h}{2}$$



$$\mathbf{y}_j^{n-1} + \left\{ -2 + h^2 \left[\frac{N^2(z_n) - \mathbf{w}^2}{\mathbf{w}^2 - \mathbf{w}_i^2} \right] k_{hj}^2 \right\} \mathbf{y}_j^n + \mathbf{y}_j^{n+1} = 0, \quad n = 1, 2, \dots, N-1$$

Boundary Condition:

$$\mathbf{y}_j^0 = 0 \quad \text{and} \quad \mathbf{y}_j^N = 0$$

Wave Equation:

$$\mathbf{A}(k_{hj}^2) \mathbf{y}_j = 0 \quad \rightarrow \quad \text{Eigenfunctions}$$

Eigenvalue Equation:

$$\det[\mathbf{A}(k_{hj}^2)] = 0 \quad \rightarrow \quad \text{Phase/Group Velocities of Normal Modes}$$

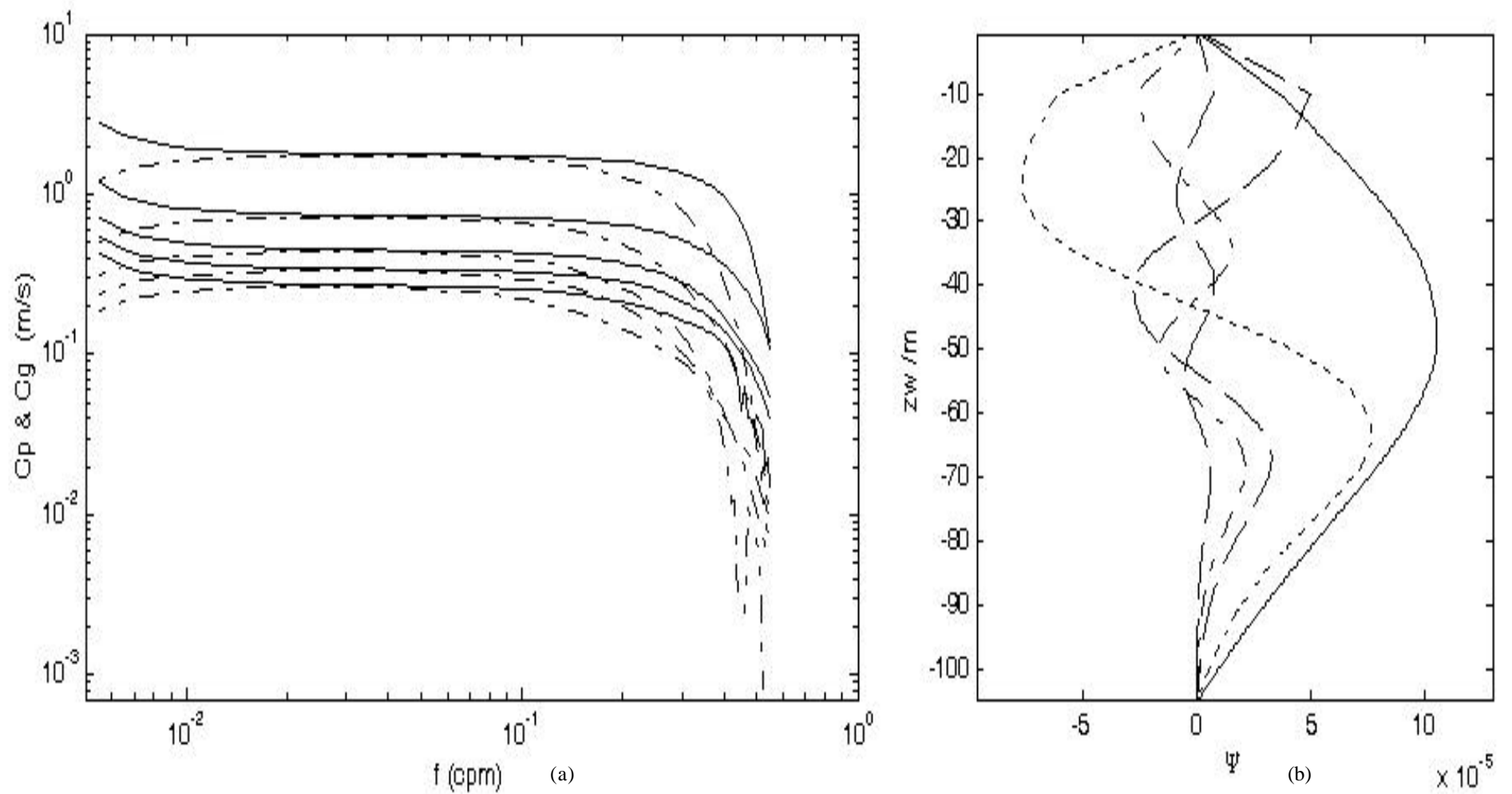


Figure 5 Phase velocities, group velocities and eigenfunctions of the first five normal modes of internal wave

At frequency of 0.05cpm, Phase/Group Velocities:

❑ 1th normal mode : 1.77m/s and 1.73m/s

❑ 2th normal mode : 0.73m/s and 0.71m/s

❑ 3th normal mode : 0.44m/s and 0.43m/s

❑ 4th normal mode : 0.34m/s and 0.33m/s

❑ 5th normal mode : 0.27m/s and 0.26m/s

$$\mathbf{y}_j = [\mathbf{y}_j^0, \mathbf{y}_j^1, \mathbf{y}_j^2, \cdots, \mathbf{y}_j^N]$$

$$\mathbf{A} = \begin{bmatrix} 1 & 0 & & & & \\ 1 & g_1 & 1 & & & \\ & 1 & g_2 & 1 & & \\ & & \ddots & \ddots & \ddots & \\ & & & 1 & g_{N-2} & 1 \\ & & & & 1 & g_{N-1} & 1 \\ & & & & & 0 & 1 \end{bmatrix}_{(N+1) \times (N+1)}$$

Here,
$$g_n = -2 + h^2 \left[\frac{N^2(z_n) - \mathbf{w}^2}{\mathbf{w}^2 - \mathbf{w}_i^2} \right] k_{hj}^2 \quad n = 1, 2, \cdots, N - 1$$

5. Conclusion

(1)The internal wave owns the feature of internal semi-diurnal tides with strong fluctuations.

(2)There exist three elevation solitons which are separated from internal tides.

(3)The mean spectrum attenuation coefficient of the vertical displacement power spectrum is about -1.5.

(4)The estimated mean group velocities of five normal modes of internal wave at frequency of 0.05cpm are 1.73m/s, 0.71m/s, 0.43m/s, 0.33m/s and 0.26m/s, respectively.

THANKS